Electric Vehicle (EV)-Grid Analysis Modeling

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Lawrence Berkeley National Laboratory

2020 DOE VTO Annual Merit Review

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Project ID: VAN028

Overview

Timeline

- Start date: October 2019
- End date: September 2022
- Percent complete: 17%

Barriers

- Indicators and methodology for evaluating environmental sustainability and cost impacts
- Relating component-level technologies to national-level benefits

Budget

- Total project funding: $750K
  - DOE share: 100%
- FY 2019: $250K

Partners

- Project Lead: LBNL
- Partners: UC Davis, Emerging Futures LLC

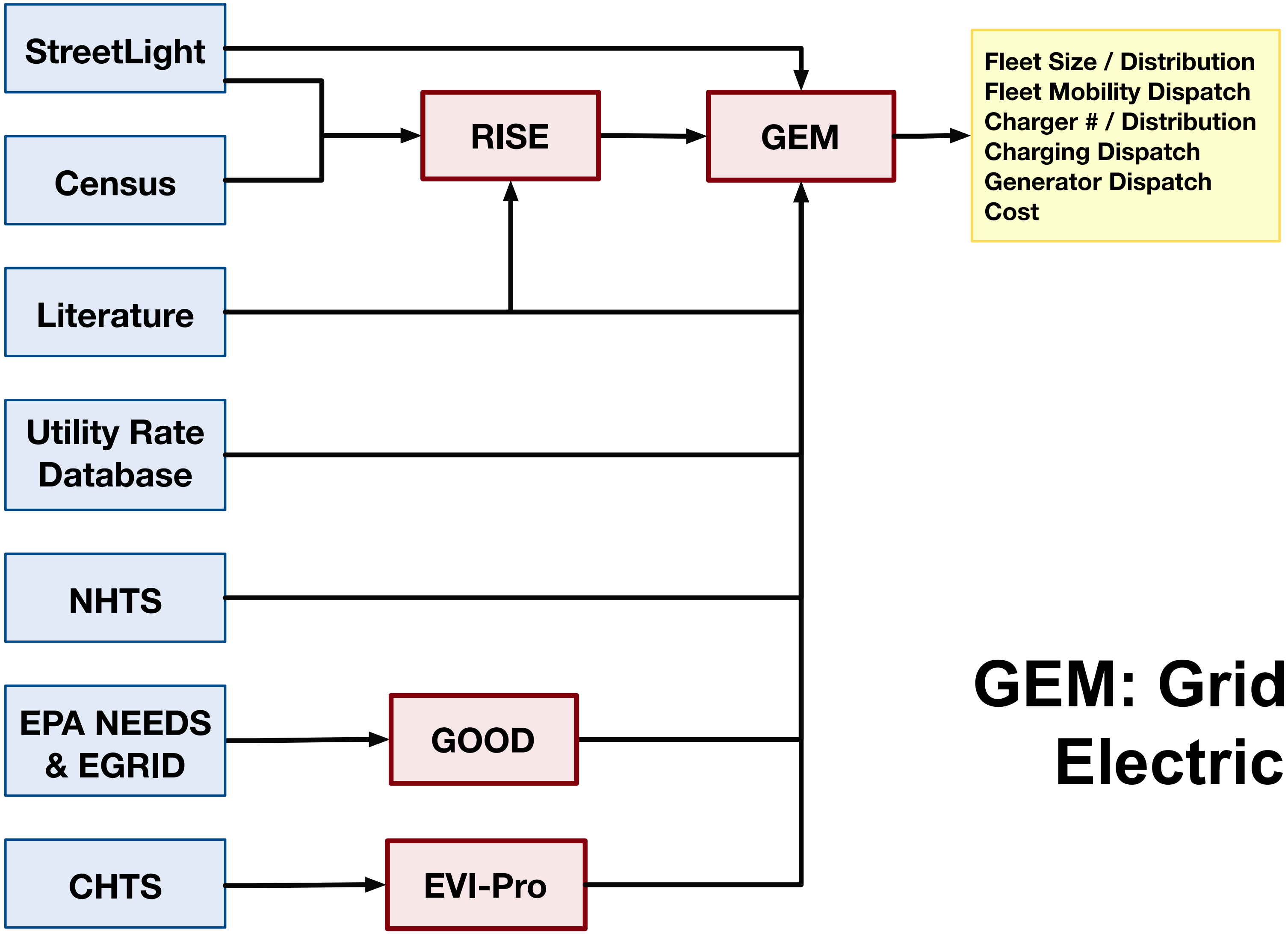
Milestones

Date	Milestone	Status
December 2019	Generate long-haul freight truck origin-destination matrix and expected truck flow on major corridors for baseline scenario	Complete
March 2020	Complete integration of SMART Mobility results into scenario assumptions including VMT rebound and modal distributions	Complete
April 2020	Submitted a journal article on grid integration benefits of SAEV fleets compared to privately owned EVs at a national level	Complete
June 2020	Produce freight truck turnover model and potential adoption curves for electric trucks. Complete initial implementation of human-driven ride hail and micromobility in GEM model.	On Schedule
September 2020	Complete one baseline and at least two additional scenarios for long-haul trucking electrification and charging demand; Complete a preliminary assessment of electrification opportunities for new mobility services and heavy-duty freight; Produce standardized outputs for use by other Analysis project teams	On Schedule

Objectives

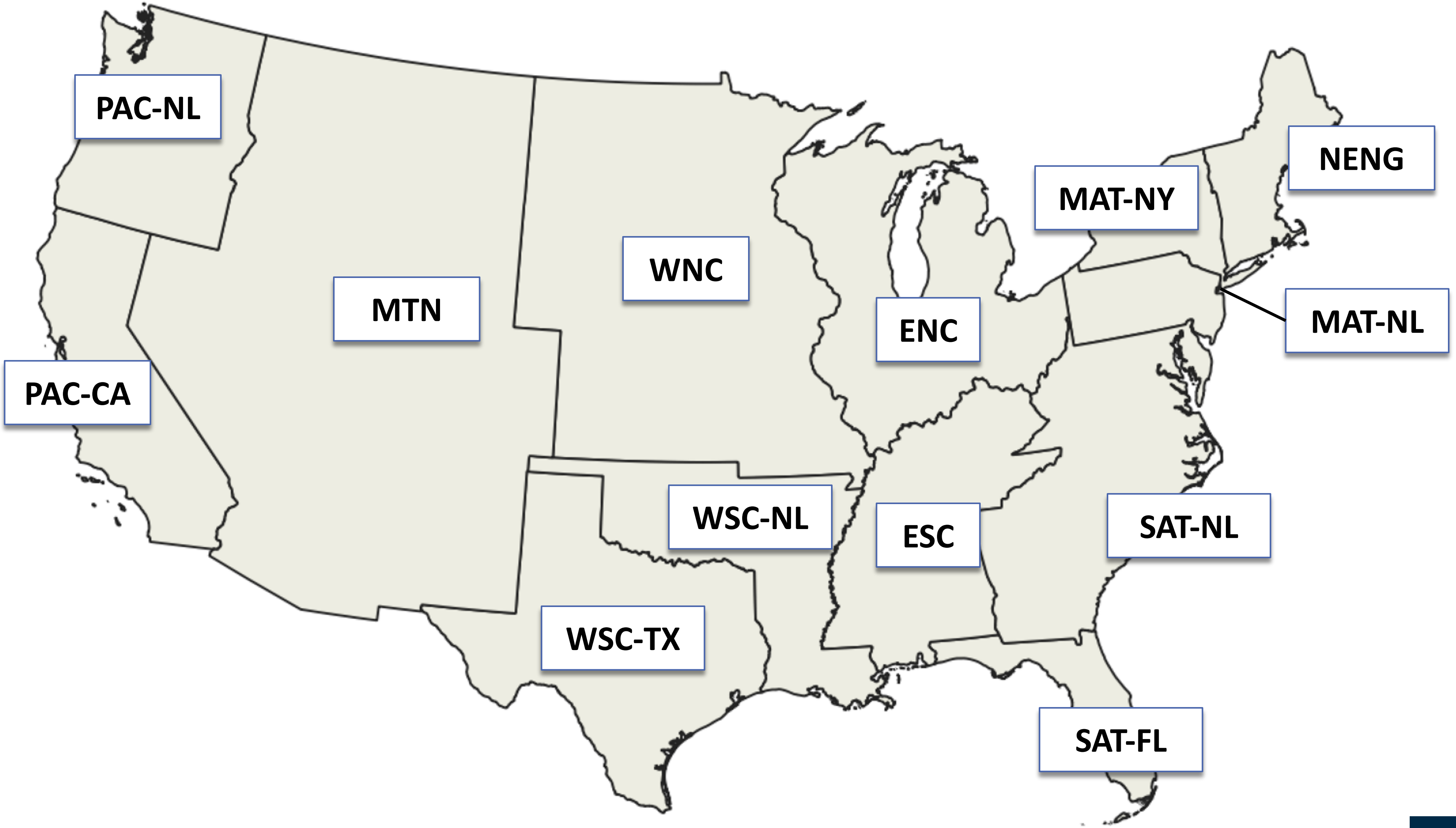
- Estimate the costs and benefits on the transportation and power systems of integrating millions of plug-in electric vehicles
  - Impact on power system generators including the curtailment of intermittent renewable energy
  - Impact on grid operating cost
  - Impact on fleet and charging infrastructure requirements
- By accounting for charging profile and load flexibility within personally owned EV fleet as well as future fleets of shared automated EVs (SAEVs) serving mobility on-demand
- The grid is simulated as dispatched, allowing the system costs to be minimized across both transportation and power sectors

GEM Model Co-Optimizes Mobility and Grid



GEM: Grid-Integrated Electric Mobility

Geographic Extent



Optimization Model

- How will firms allocate shared automated EVs to serve mobility demand?
  - Larger battery capacities or smaller?
  - Faster chargers or slower?

- How will charging be scheduled in response to time-varying cost of electricity?
  - More vehicles => more flexibility but at a higher fleet cost

- How will electricity generators be dispatched in light of the flexible load?

Problem Formulation

- Objective:
  - Minimize operational cost of serving demand + generating electricity + amortized fleet and infrastructure costs
- Decision Variables:
  - # of Vehicles in Fleet (by range, e.g. 75 mile vs 150 mile)
  - # of Chargers to Install (by power capacity)
  - Which vehicles serve which trips
  - Which vehicles charge, when, and at what power level
  - Which electricity generators are dispatched
  - How much electricity is imported/exported across regions

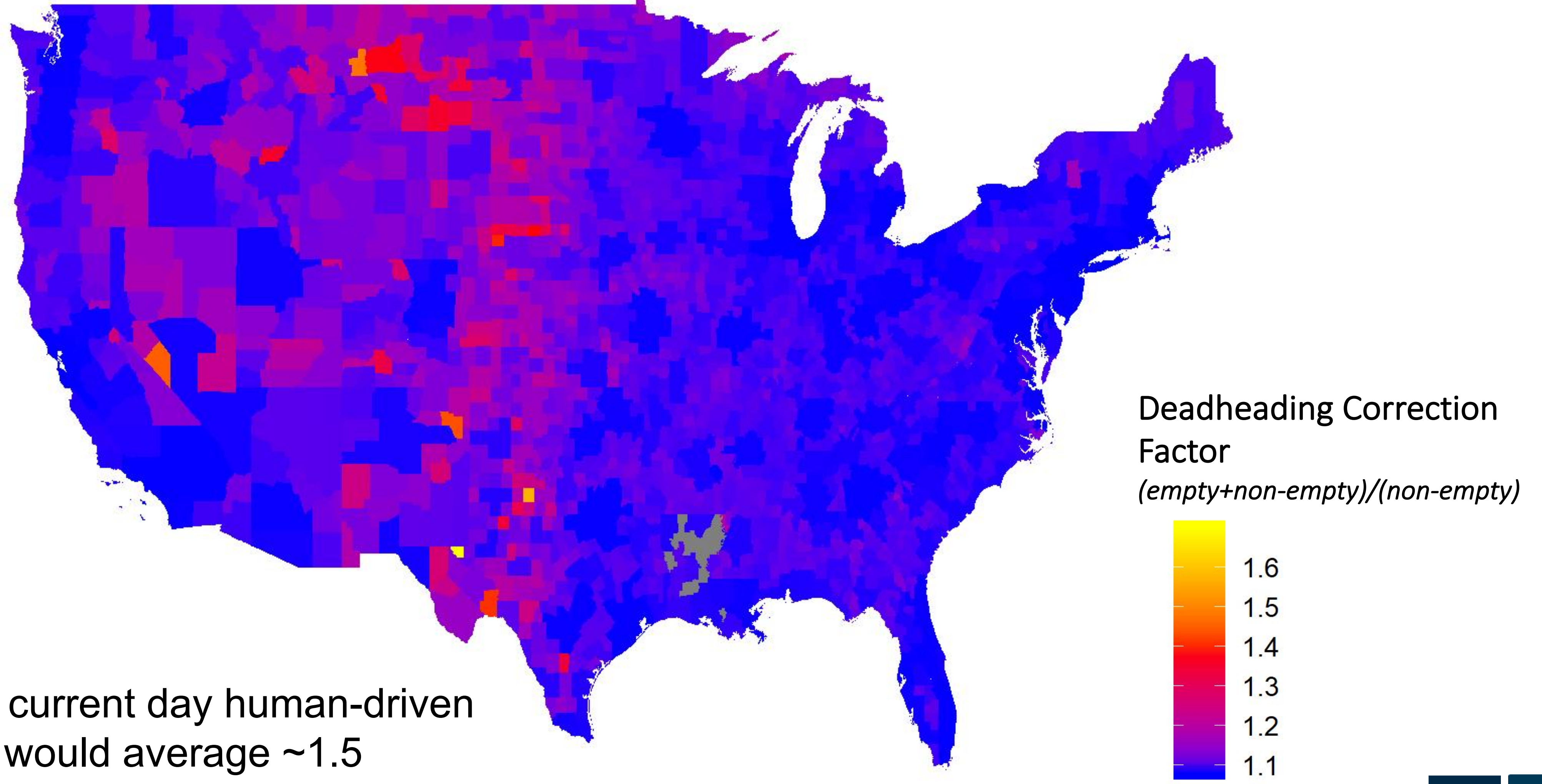
(Non-linear Convex Program)

Problem Formulation

- Constrained to:
  - All mobility demand is served
    - Vehicles allocated to demand within a time period based on
      - average sharing factor (passengers per vehicle)
      - distribution of speed
      - distribution of trip distances
      - ratio of total VMT / with-passenger VMT
  - Number of vehicles charging < number of charging plugs
  - Energy conservation
  - Batteries begin/end at full
  - Generation constraints on ramping and transmission

Extrapolation to National Scale

If Shared, Autonomous, Electric Vehicles (SAEVs) serve all driving trips, high trip density leads to low deadheading in most areas



For reference: current day human-driven ride hail fleets would average ~1.5

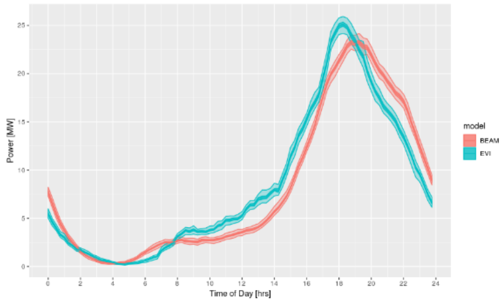
Aggregate Private EV model

Analogous Approach to CA Analysis

Simulated Mobility / Charging
- EVI-Pro finds lowest cost charging schedule subject to assumptions on chargers levels & driver preference

Charging Sessions
- When and where for each charging session (fast, home or workplace etc.)

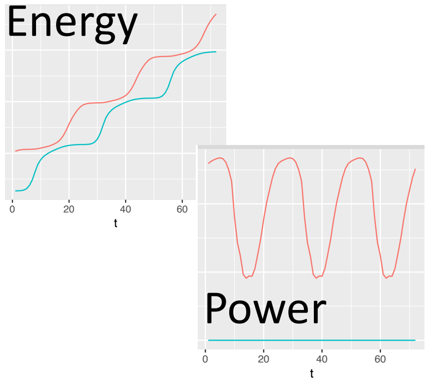
Aggregate Constraints
- Develop aggregate model in each region
- Coordinate EV charging power profiles subject to charging constraints



EVI-Pro + Post-Processing & Sampling Tool by HSU

No.	Arrive time	Leave time	Arrive soc	Leave soc	power
1	18:00	22:00	0.4	0.9	6.6
2	15:00	17:00	0.6	0.8	3.3
3	11:00	14:00	0.7	0.6	6.6
…	…	…	…	…	…
N	19:00	07:00	0.3	1	6.6

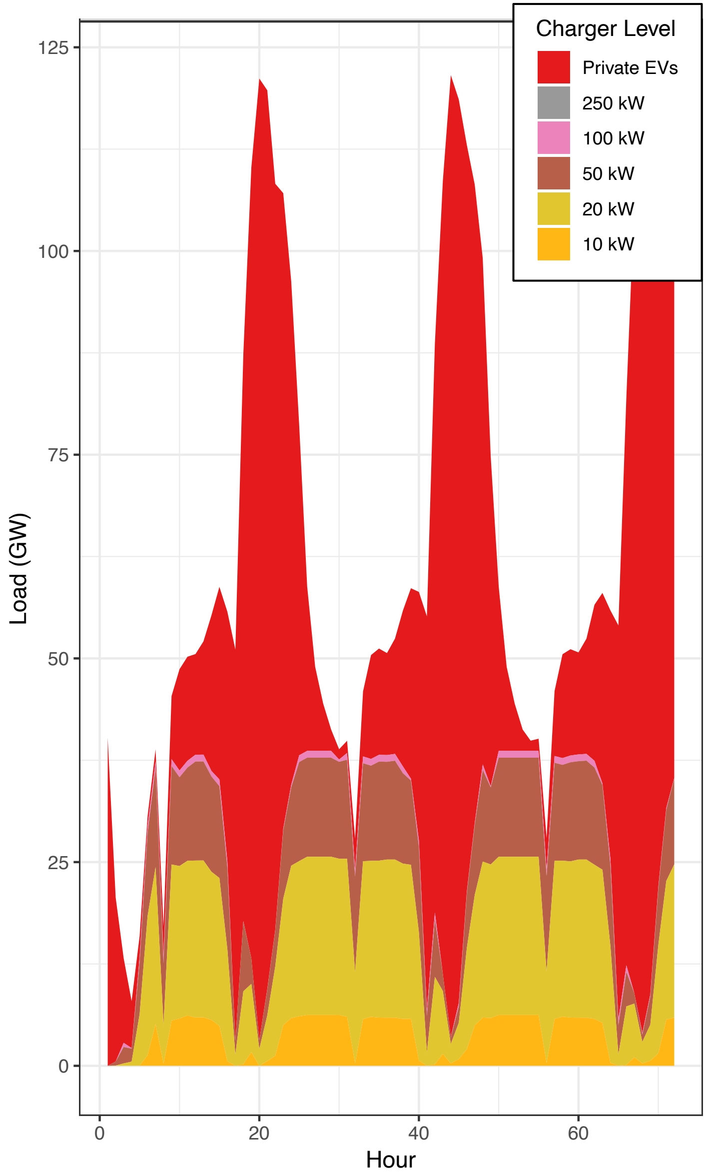
Individual EV Charging demands

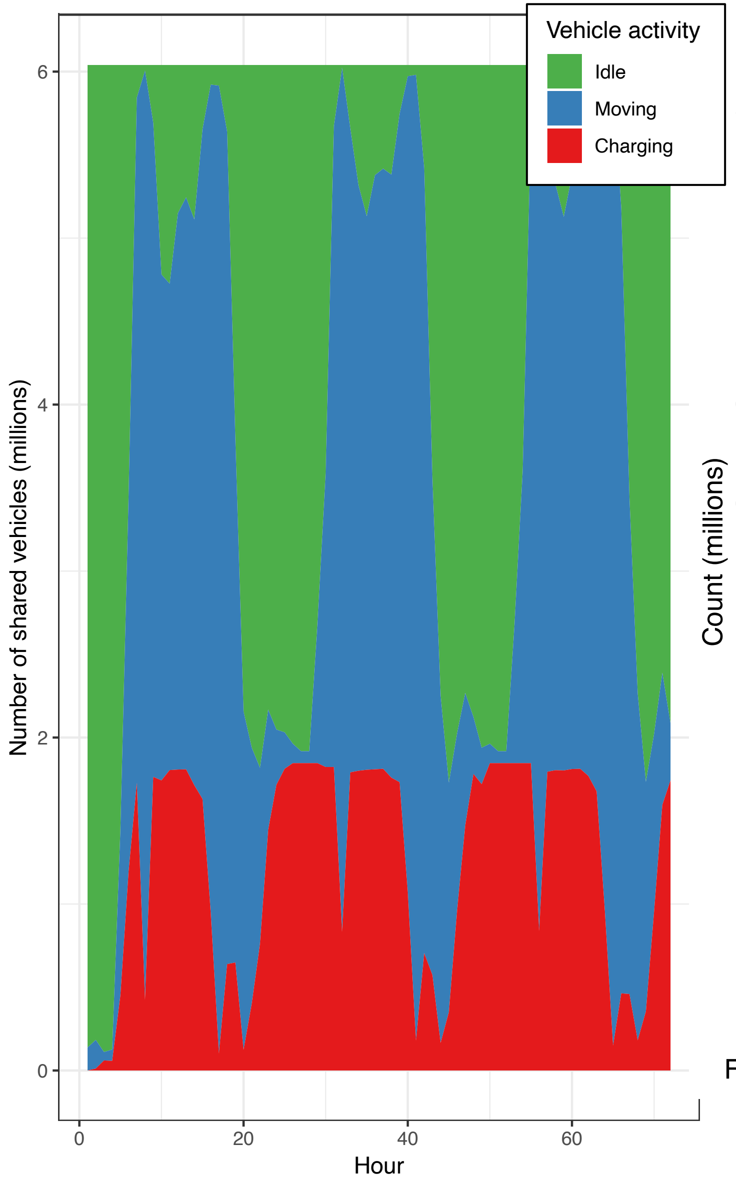


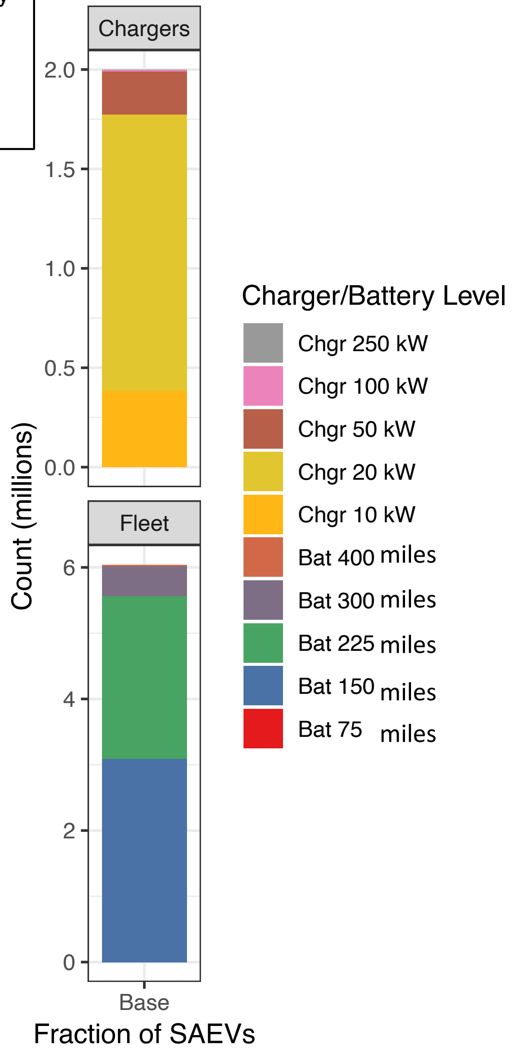
Aggregate EV charging demand model

Baseline Charging Is Heterogeneous

Accomplishment

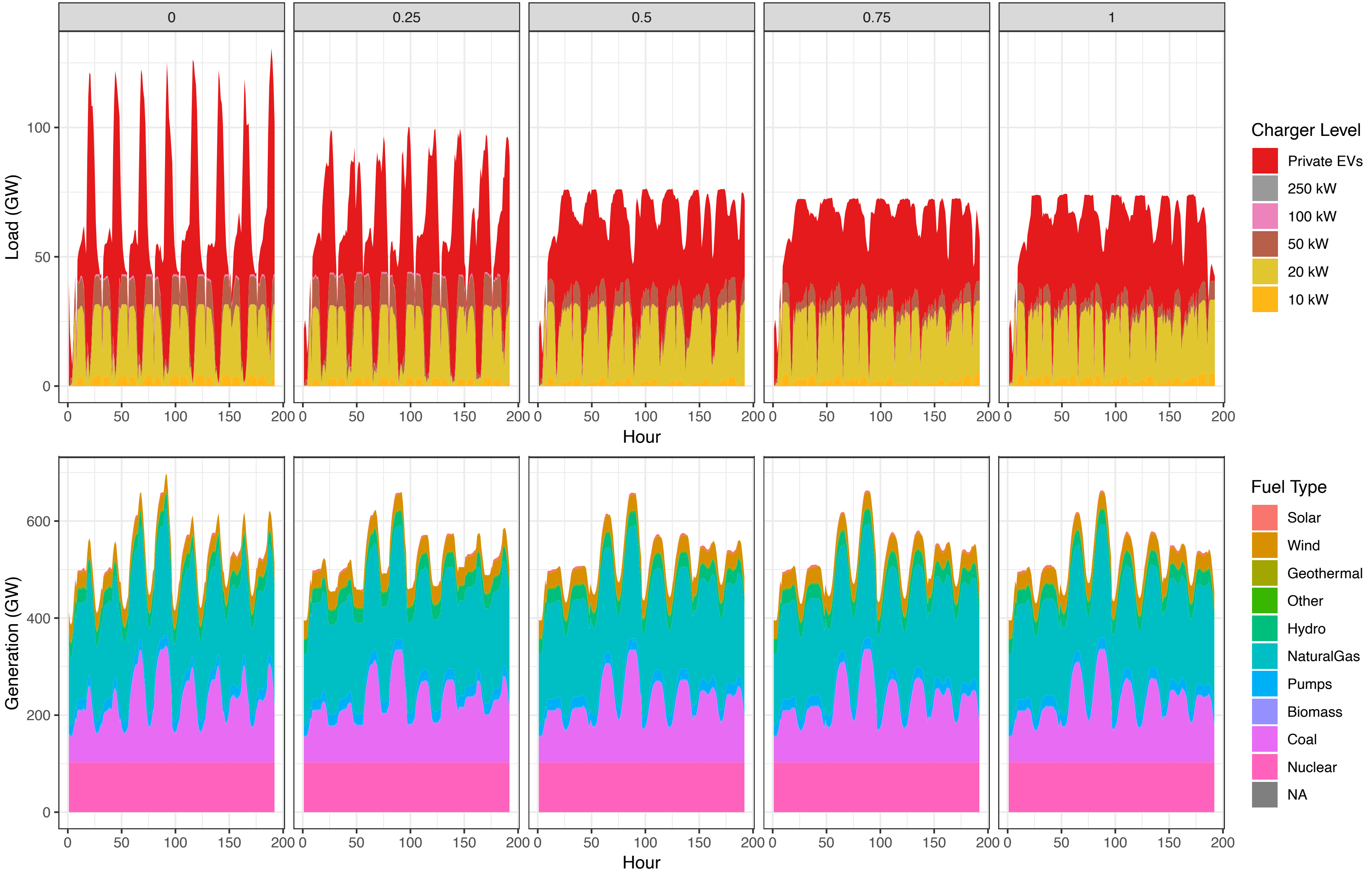






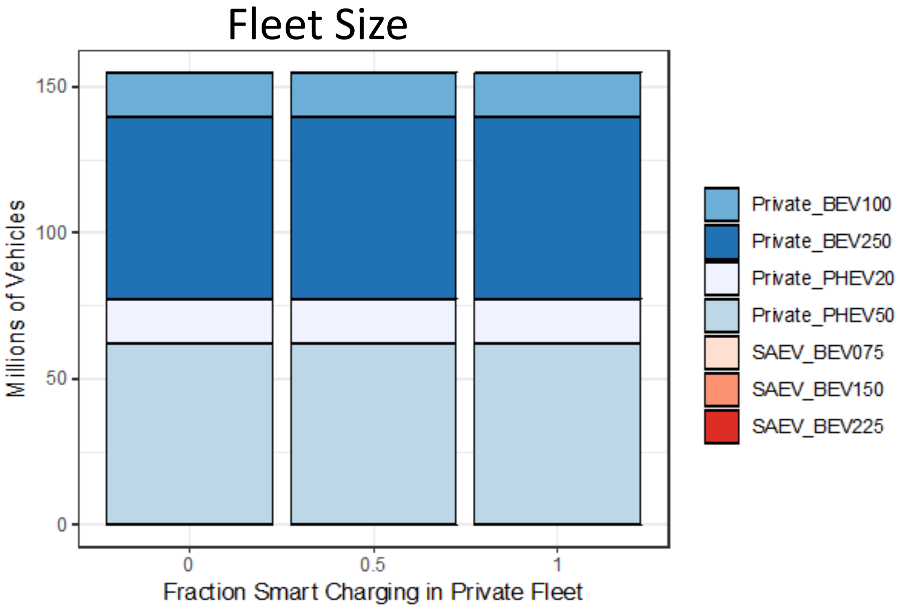
Smart Charging Smooths National Load

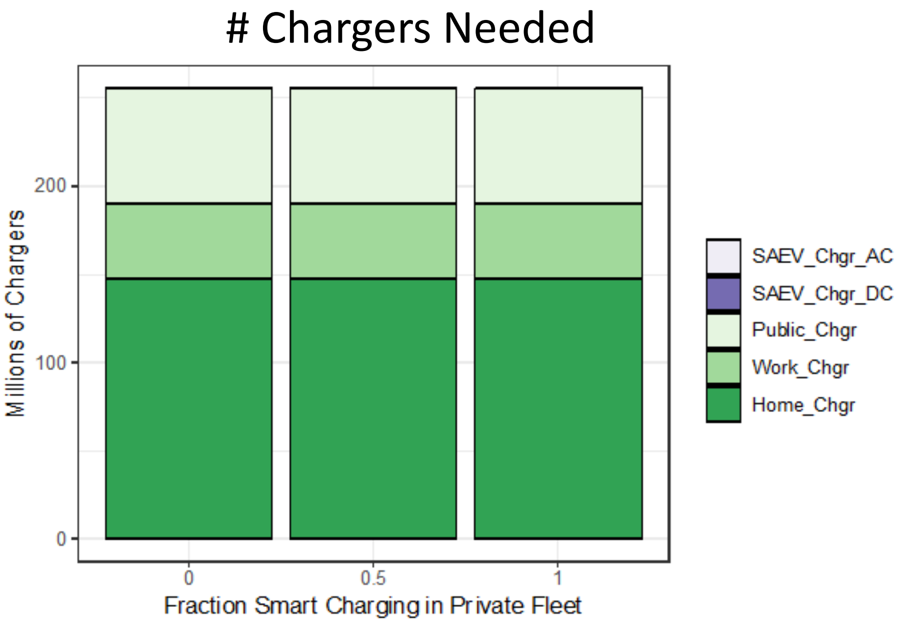
Accomplishment

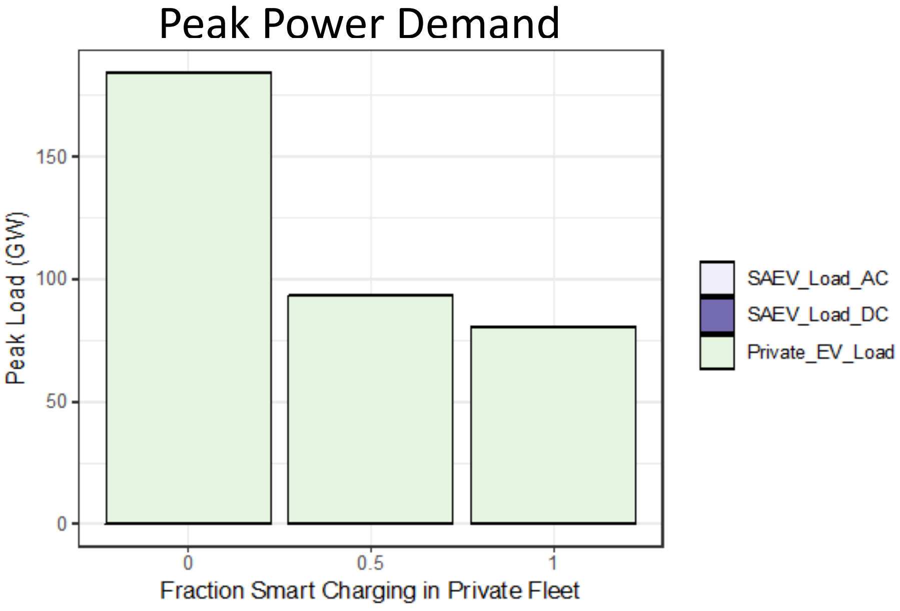


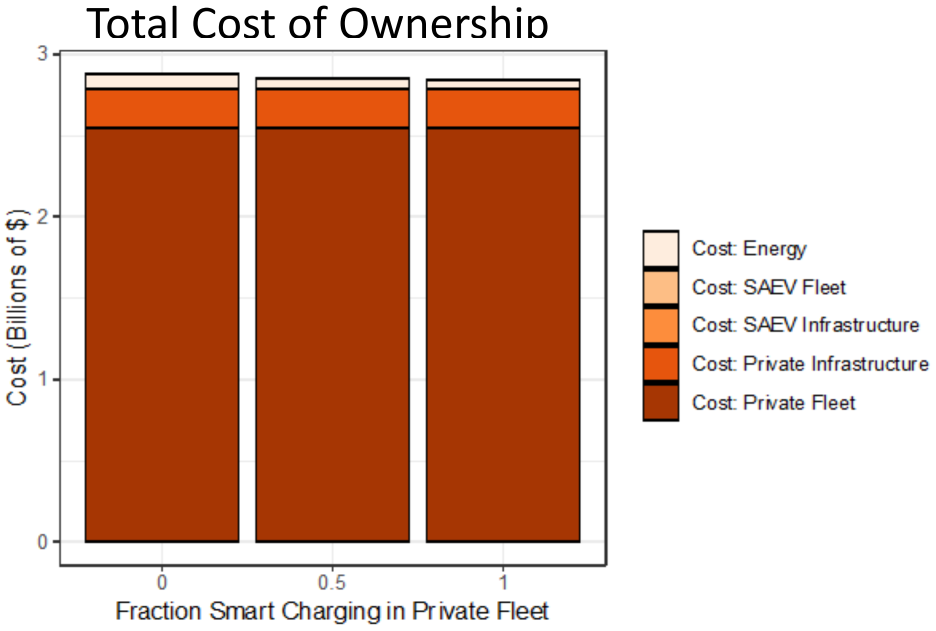
Smart Charging with Private Fleet Cuts Peak Load in Half but Cost Savings are Small relative to TCO

Accomplishment







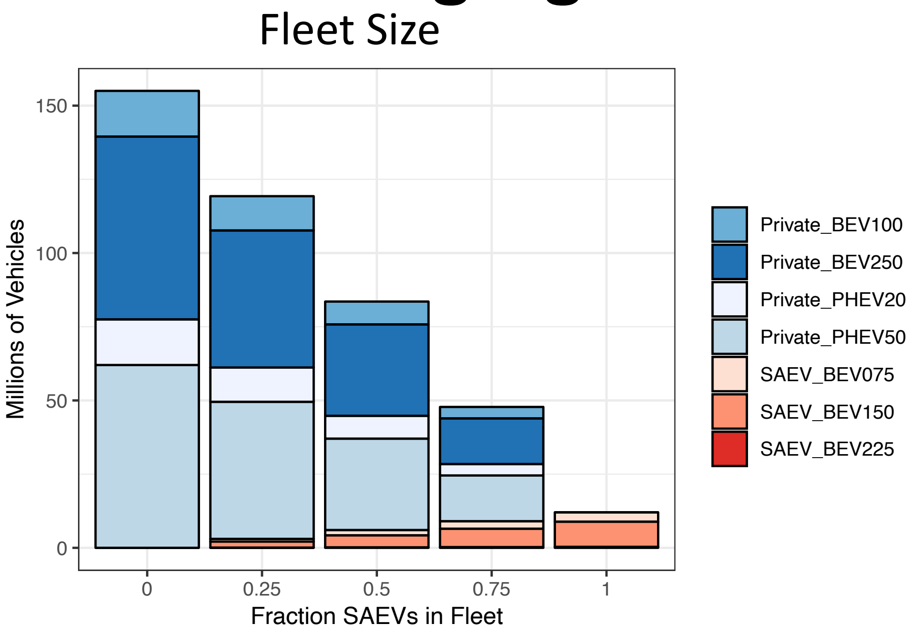


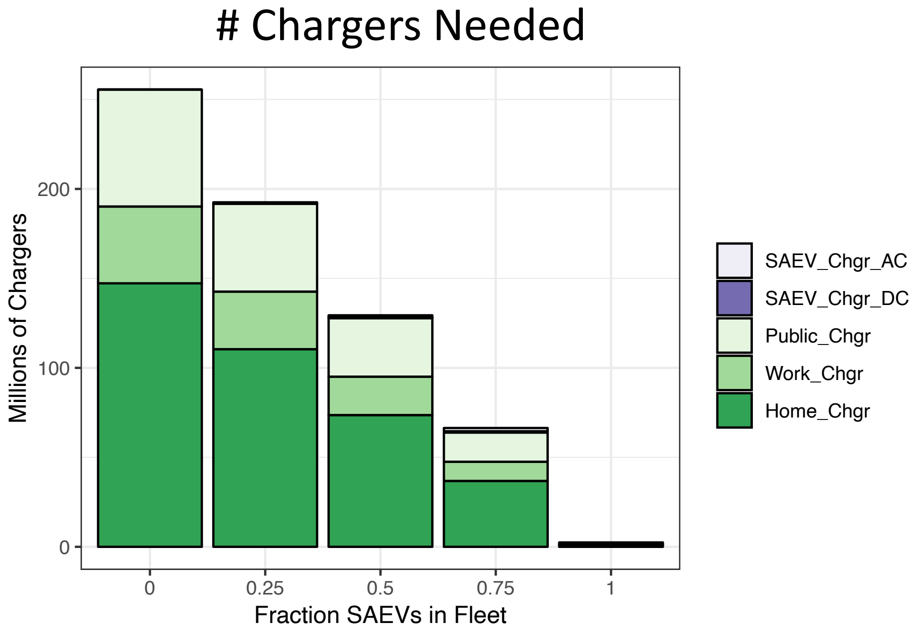
ENERGY TECHNOLOGIES

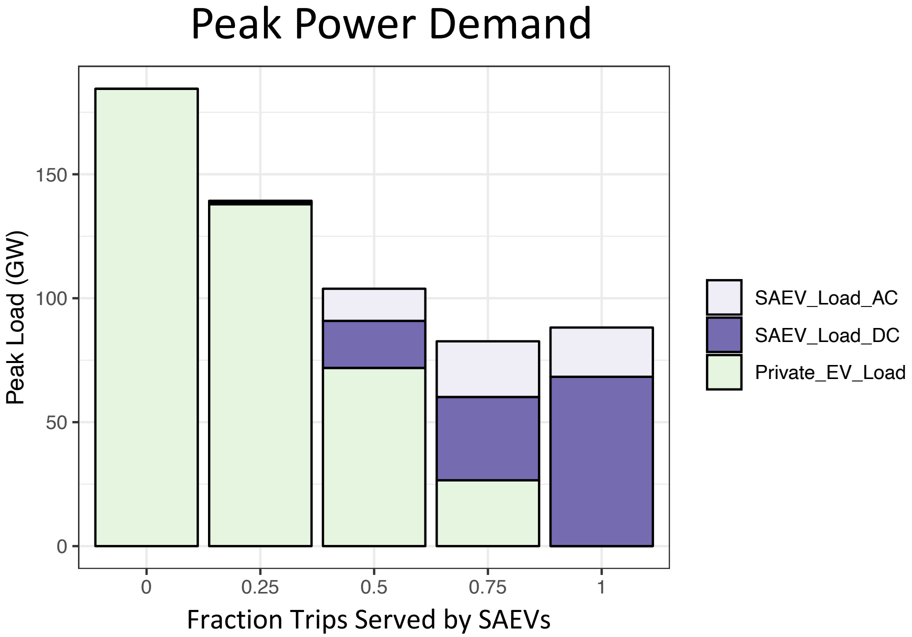
BERKELEY LAB

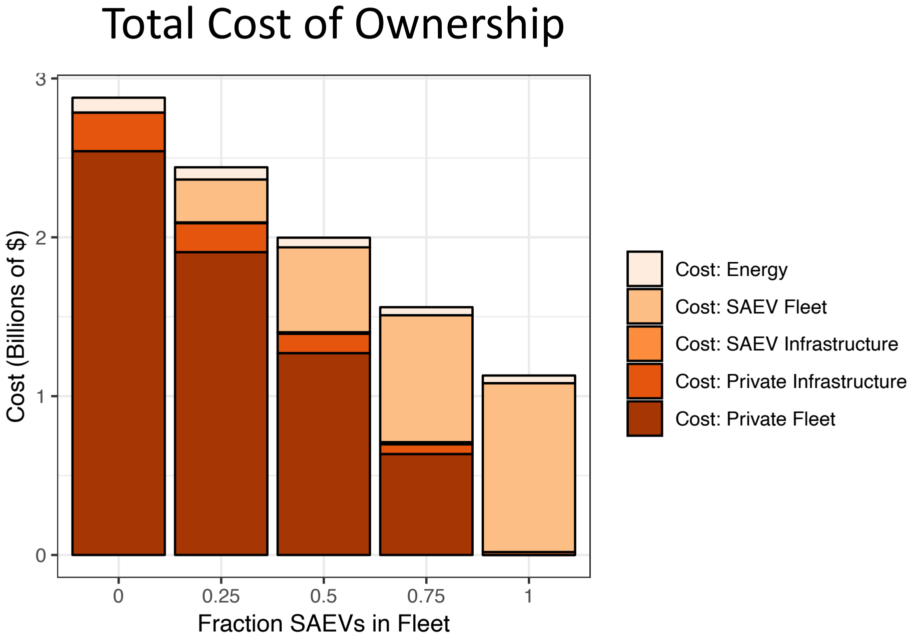
Peak Load Reduction Is about the Same as Private Vehicle Smart Charging

Accomplishment



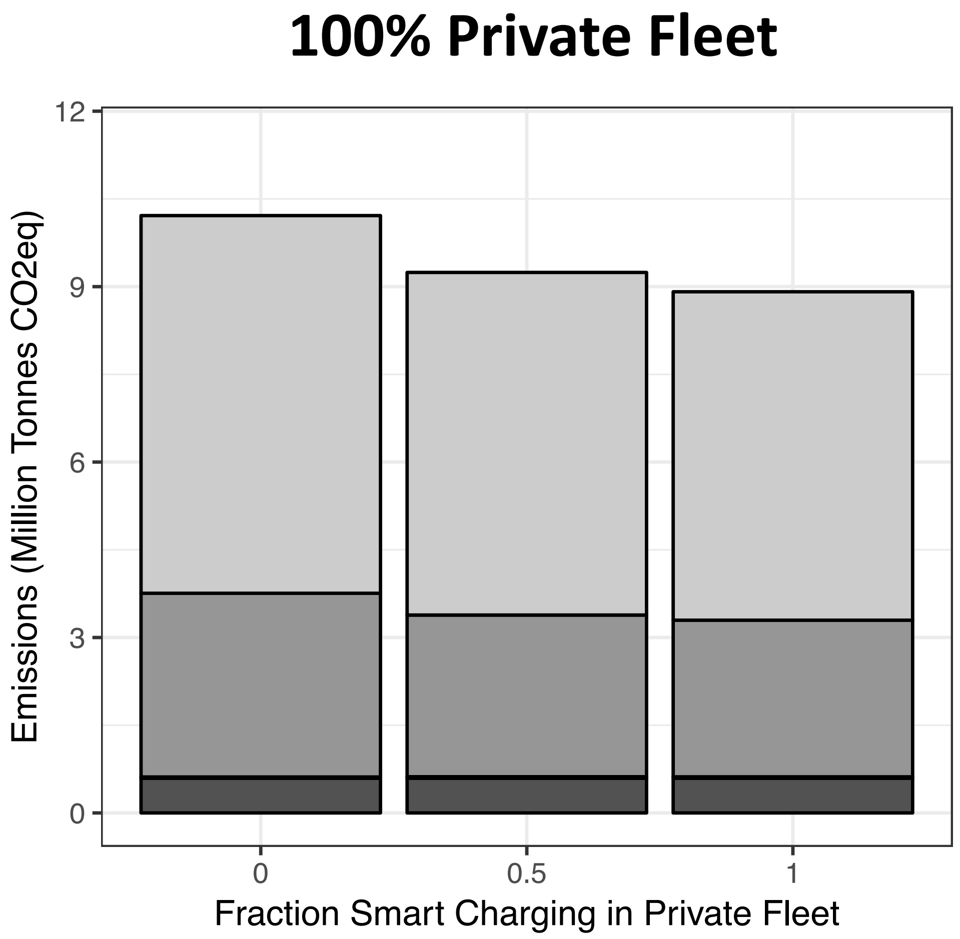


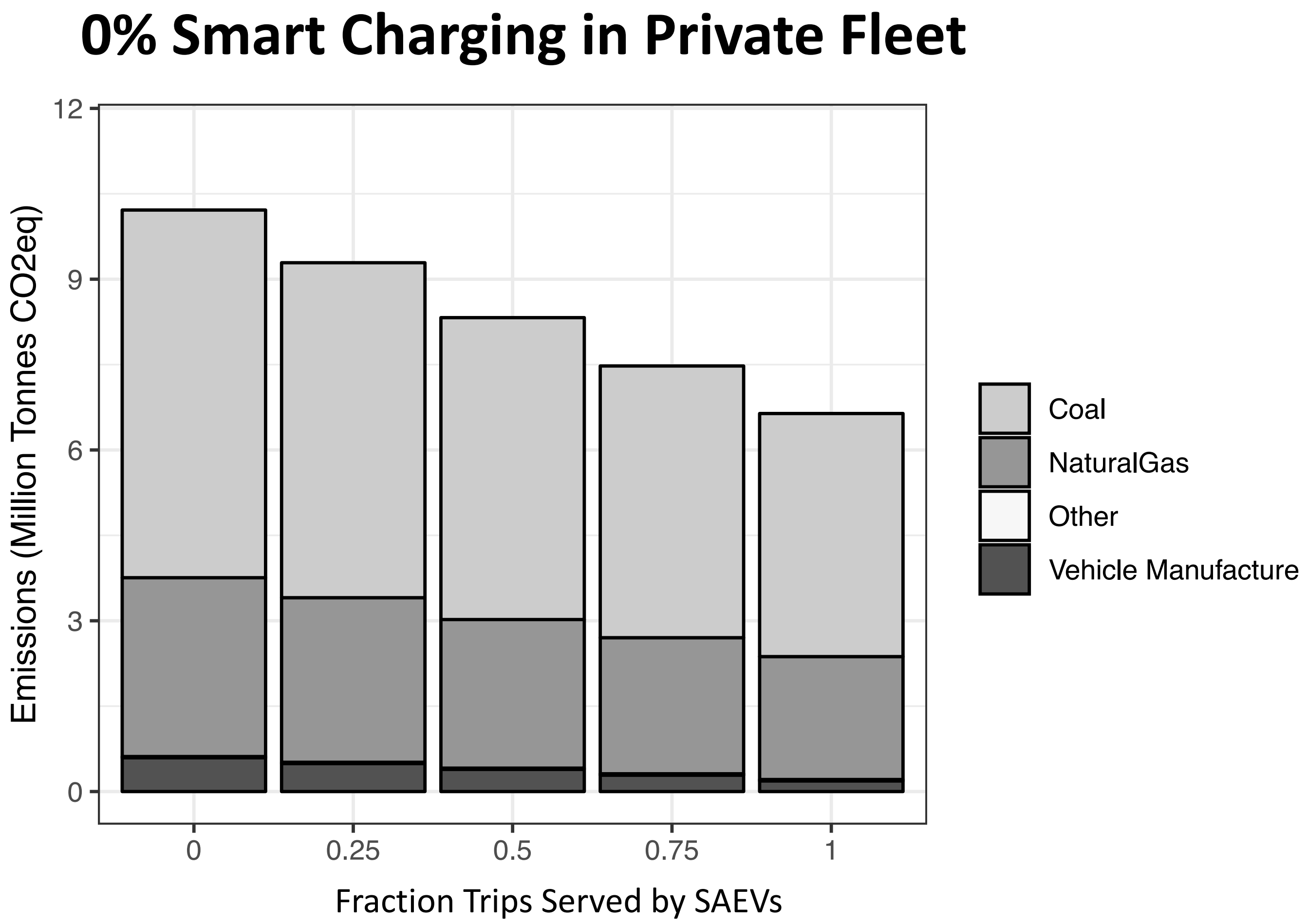




SAEVs Reduce More Emissions than Smart Charging of Private EVs

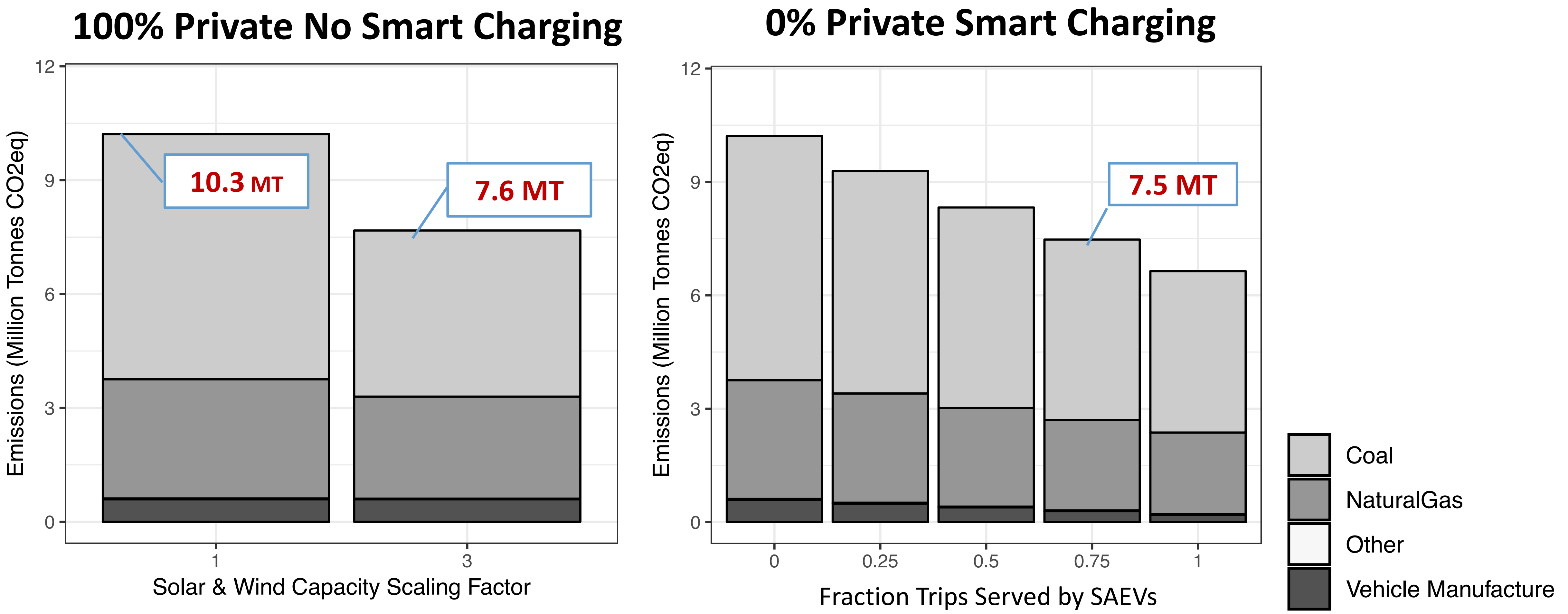
Accomplishment





A 75% SAEV Fleet Would Produce Equivalent Emissions as A 200% Increase in Solar & Wind Generation

Accomplishment



Other Notable Results

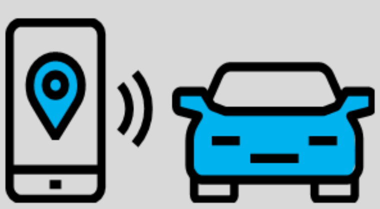
Accomplishment

- If 100% of mobility currently served by light duty vehicles were instead served by SAEVs:
  - a fleet of 12M vehicles could service the demand, or about 11% of 111 million passenger cars in the U.S. in 2017.
  - requiring 3M chargers of varying power capacities
  - increasing electricity demand by 1500 GWh/day or 11% of 2017 U.S. demand
  - increasing peak power demand by 77 GW or 11% of 2017 U.S. peak demand

Mid-term and Long-term Transition Scenarios

- We model the near-term, mid-term, and long-term penetration of electrified private and shared vehicles based on DOE-VTO's SMART scenarios.

HIGH SHARING, PARTIAL AUTOMATION (A)



Mid-Term Future
A2 - Business-as-usual vehicles
A3 - DOE vehicle technology success

HIGH SHARING, HIGH AUTOMATION (B)

Long-Term Future
B5 - Business-as-usual vehicles
B6 - DOE vehicle technology success

LOW SHARING, HIGH AUTOMATION (C)

Long-Term Future
C5 - Business-as-usual vehicles
C6 - DOE vehicle technology success

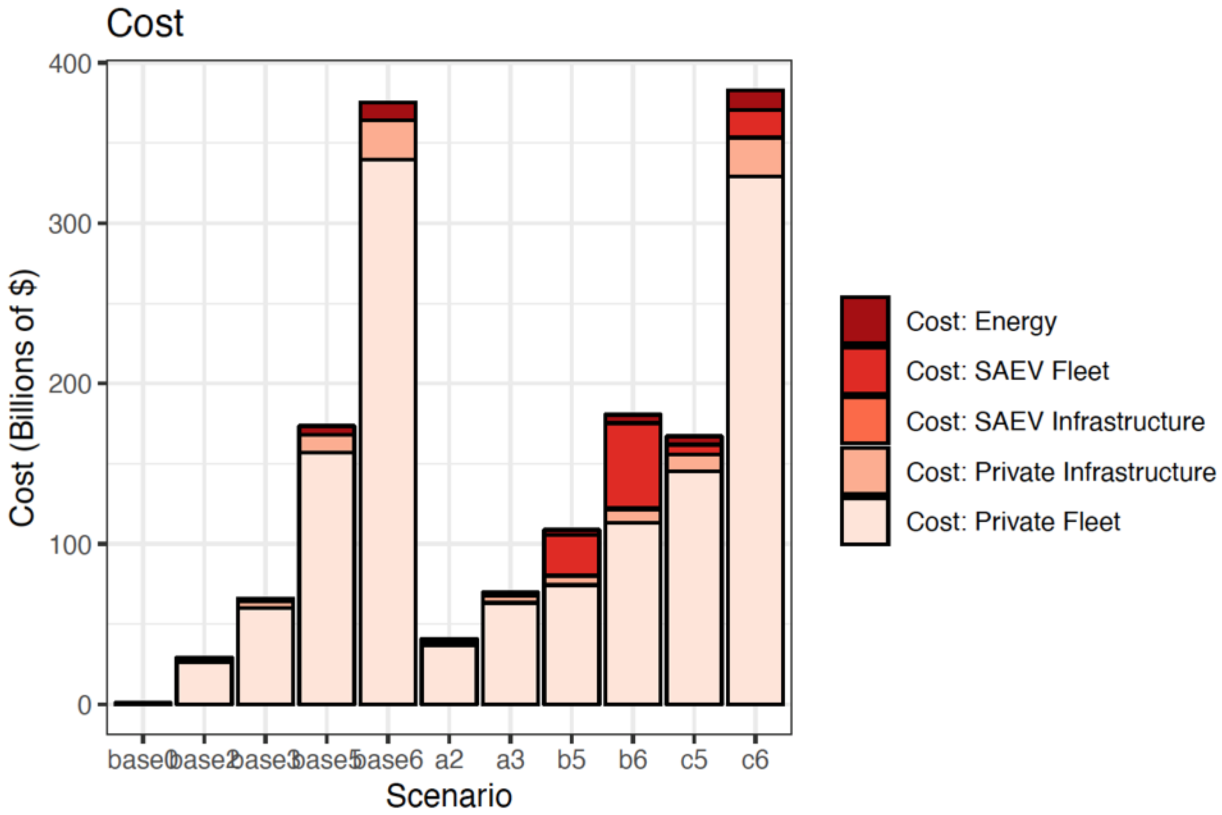
BASELINES Base0 – Present Day

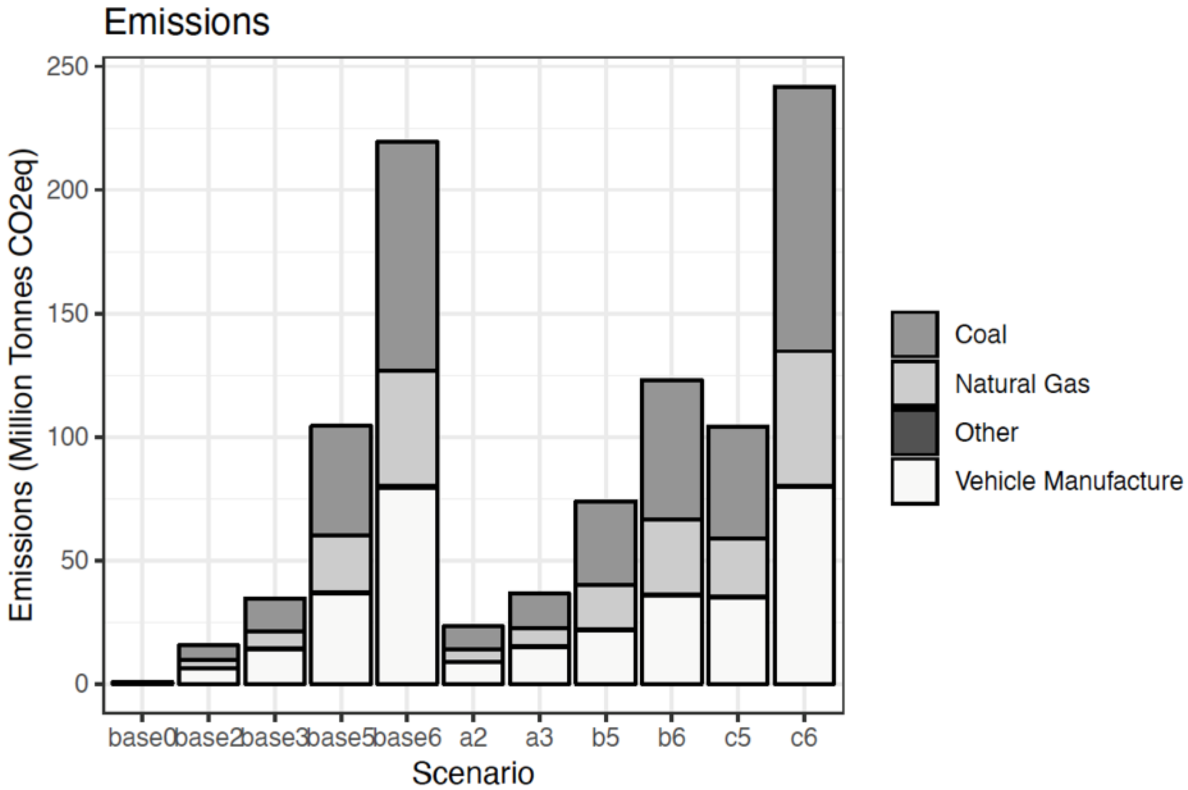
Base2 – Mid-Term, BAU Vehicles
Base3 – Mid-Term, Tech Success

Base5 – Long-Term Future, BAU Vehicles
Base6 – Long-Term Future, Tech Success

High-Sharing Leads to Large Reductions in Cost and Emissions

- System expenditure and total greenhouse emissions of electric vehicles increase substantially in the projected futures as a result of increased penetration. However, high-sharing scenarios (B5, B6) lead to a factor-of-two cost reduction and 25-100% emissions reductions compared to low-sharing scenarios (C5, C6).





Response to FY19 Reviewer Comments

- **One reviewer highlighted the relevance and impact of the work**
- *“The reviewer remarked that this is a very ambitious project with an approach to match, and commended the researchers on a straightforward methodology that helps provide incredible insights into the benefits and costs of a world with SAEVs. […] The [reviewer] indicated that the Slide 6 question about faster or slower chargers is a major technology decision that charging system providers and local and state governments are wrestling with at the moment.”*

- **Response**
- We thank the reviewer for illustrating how the modeled scenarios is relevant for the real-world decisions made by state and local governments. We will continue to update the model and perform the analysis to stay impactful.

Response to FY19 Reviewer Comments

- **Several reviewers suggested modeling transition scenarios**
- *"The reviewer noted that it was unclear why the focus of certain examples has been 100% shared connected and EV fleets instead of focusing more on transitions."*
- *"The analysis team could focus more on the transitions to electric, shared, and connected and automated vehicle fleets, instead of setting off directly to evaluate 100% transition scenarios, because the former are more likely to be pertinent to DOE's short run evaluation needs."*
- *"The assumption that all vehicles in some future scenario are electric, fully shared, and fully autonomous is an ideal situation. The reviewer explained that these assumptions can skew results or lead to obvious conclusions (i.e., smart charging leads to smoother grid loads, or fewer vehicles and less electricity are required if transportation is 100% electric, shared, and autonomous)."*
- **Response**
- We agree with these suggestions. In response, we have modeled the near-term, mid-term, and long-term penetrations of electrified private and shared vehicles based on the insights from DOE-VTO's SMART consortium and summarized findings on pp.19-20 in this poster.

Response to FY19 Reviewer Comments

- **Several reviewers were concerned about the computational efficiency**
  - *"This reviewer agreed with the research team that tackling the computational efficiency needs to be a high priority for next steps. Doing so will allow great numbers of insights on the optimized SAEV world."*
  - *"As the team recognized, the reviewer commented that the optimization problem quickly becomes too large to solve."*

- **Response**
  - We took this task of improving computational efficiency as a top priority. We are now able to run the GEM model for 14 days (consisting of representative and extreme days for each season in a year) within a reasonable running time. This improvement enables our results to be more representative and relevant.

Response to FY19 Reviewer Comments

- **One reviewers was concerned about the lack of publications**
  - *"This reviewer said the project appears to have made good progress, but publications and presentations are lacking."*

- **Response**
  - We have published a peer-revised journal paper last year.
    - *Sheppard, Colin J. R., Gordon S. Bauer, Brian F. Gerke, Jeffery B. Greenblatt, Alan T. Jenn, and Anand R. Gopal. "Joint Optimization Scheme for the Planning and Operations of Shared Autonomous Electric Vehicle Fleets Serving Mobility on Demand." Transportation Research Record, April 13, 2019, 0361198119838270. https://doi.org/10.1177/0361198119838270.*
  - We have submitted an article to a peer-review journal and the article is currently under review.

Partners and Contributors

- UC Davis
  - A project partner
- Emerging Futures LLC
  - A project partner
- Argonne National Laboratory - GREET
  - We have delivered emissions outputs from GEM to the GREET team for use in their FY19 efforts
- NREL
  - Source for modeled private EV charging data
- Humboldt State University Schatz Energy Research Center
  - Contributed to data processing of private EV charging data

Remaining Challenges and Barriers

- Peer-review publication process
  - Article has been submitted and will undergo an external peer review process. We will address reviewer comments to ensure our manuscript maintains a high-level of scientific standards. Publication will allow for our work to be disseminated more broadly to the scientific community.

- Providing an open-access version of GEM
  - We are planning to publish our GEM model on GitHub to provide the public access to our tool so that results can be replicated and/or new scenarios can be generated
  - User tutorial to allow for ease of access and use
  - Flexible input files to allow for customization of scenarios

Proposed Future Research

- FY 2020
  - We will produce freight truck turnover model and potential adoption curves for electric trucks.
  - We will add representations of long-haul truck electrification and generate a set of results for long-haul trucking electrification scenarios and charging demand.
  - We will complete initial implementation of human-driven ride hail and micromobility in GEM model.
- Beyond FY 2020
  - We will add full representations of transportation electrification for emerging services (e.g. long-haul trucks, TNC, micro-mobility) in the GEM model.

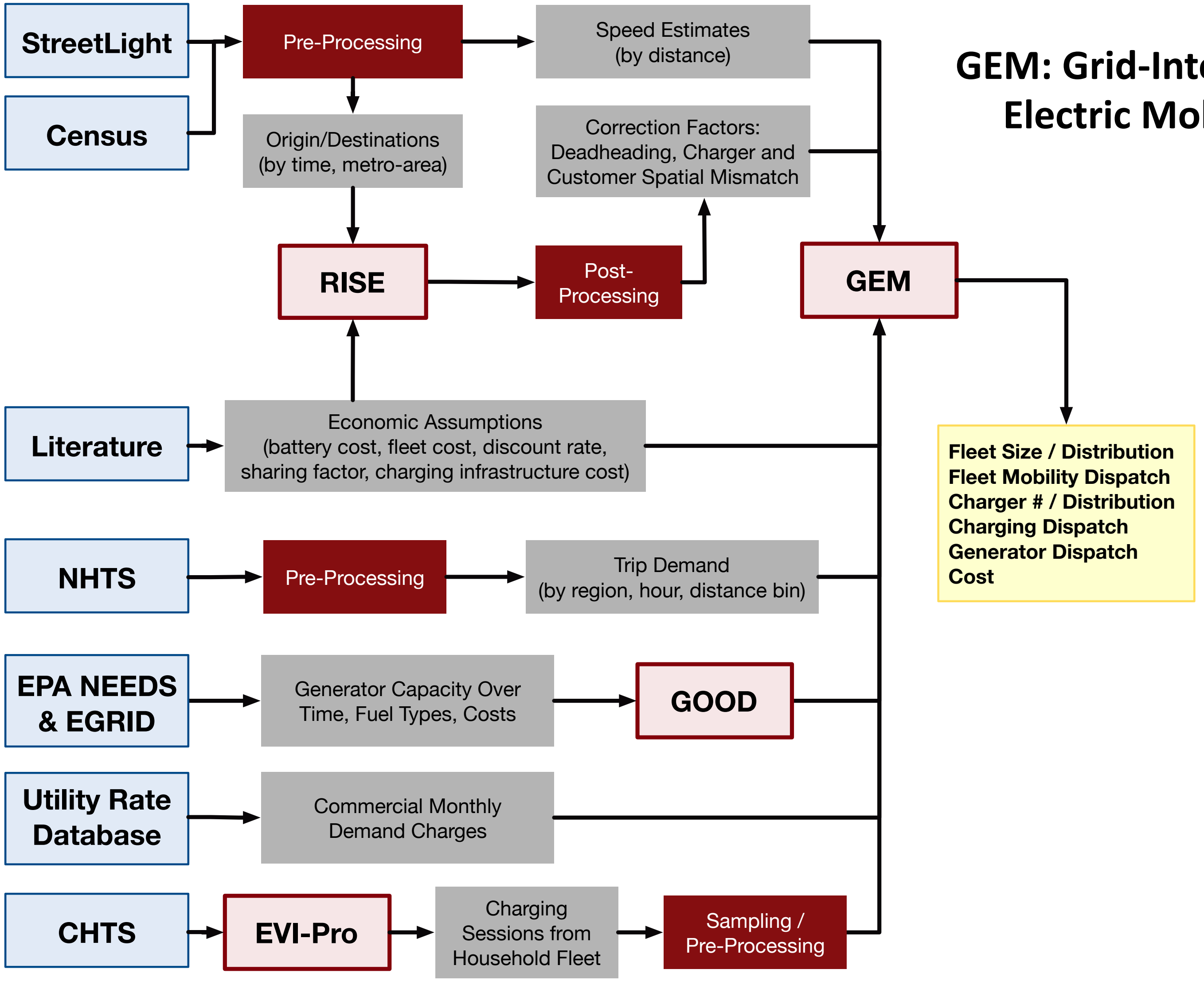
Any proposed future work is subject to change based on funding levels

Summary

- Approach – outlined technical details of optimization and associated constraints of the system
- Technical Accomplishments/Progress – finalized integration of mobility and grid modeling, comprehensive results for publication, represented SMART Consortium scenarios
- Collaboration – partners with universities and other national labs
- Future Research – adding TNC, micro-mobility, heavy-duty
- Relevance – extending VTO Benefits Analysis to include the upstream costs and benefits of EVs to the grid
- Resources -- given our current resources we have been successful at accomplishing our goals to date

TECHNICAL BACKUP SLIDES

GEM Model Co-Optimizes Mobility and Grid



GEM: Grid-Integrated Electric Mobility